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ESTIMATION OF THE CRUSTAL THICKNESS AND DISCONTINUITIES IN PARTS OF SOUTHERN BENUE TROUGH NIGERIA, USING GRAVITY DATA.

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ABSTRACT

This paper seeks to estimate the crustal thickness of the study area and to ascertain the magnitude of tectonic stability. The Bouguer gravity data were transformed from the space domain to the wave-number domain by means of a Fast Fourier Transform (FFT) to analyze the frequency content of the information. Results of average Crustal thickness obtained by using the formulae developed by Demenistskaya (HD), Woolard (HW), and Woolard and Strange (HWS) range from 20.01 to 41.24 km, with a mean value of 31.58 km, while the average crustal thickness estimated by spectral analysis ranges from 15.99 to 33.34 km. Other discontinuities have the following depth ranges: The Conrad discontinuity ranges in depth from 5.60 to 13.20 km, the depth to basement ranges in depth from 4.28 to 8.39 km, while the depth to intrusion ranges in depth from -3.45 to 4.42 km. Notably, the crustal thickness in the study area is considerable, with evidence of thinning observed within the Benue trough. A comparison with countries prone to earthquakes reveals that most of them have greater crustal thicknesses, implying that crustal thickness alone is not a definitive indicator of tectonic stability. The instability observed in regions of Nigeria experiencing tremors may be due to localized subsurface faults.

Keywords: Power spectral, Bouguer Anomaly, Conrad discontinuity and Moho discontinuity.

1. Introduction

The crustal thickness refers to the distance between the Earth's surface and the Moho. A seismologist- A. Mohorovicic studied the Earth using waves from an earthquake on October 8, 1009 in the Kulpa Valley, Croatia. He observed two P-waves and two S-waves and concluded that the first P- and S-waves had encountered an anomalous material that caused some of their energy to be reflected to the surface and that the velocities of P- and S-waves increased abruptly below a depth of about 50 km. (Don, *et al*., 1933). This change in the speed of P and S waves signifies a change in material and that area become known as the Mohorovivic discontinuity: 'Moho' or M. discontinuity is the depth separating the crust from the mantle. 'Moho' depth as well as its composition varies in different parts of the continents. The crustal thickness is generally greater under mountain regions than it is under lowlands. Upper crust material is made up of silica

and aluminium, thus the upper crust is sialic in composition. According to Walter (2003), the crust at the continental interior is within 40 to 45 km thick and 30 km thick at the ocean-continental margin. Few regions is thicker than 50 km and is restricted to a few regions such as the Tibetan plateau of western China, the Andes of western South America, and the Precambrian shield of southern Finland.

Crust under Ocean: The rocks of the oceanic crust rocks are composed primarily basalt rocks. The size of the crustal thickness of any area influences the degree of tectonic stability of the area.

Based on seismic wave velocities, the oceanic crust is not layered and is appreciably thinner than the continental crust. The size of the crustal thickness of any area influences the degree of the tectonic stability of the area. Accurate Crustal thickness estimates are necessary for calculating components of topography that are compensated isostatically (Fishwick and Basotw, 2011). Tremors have been occurring in Nigeria which hitherto had been erroneously considered to be aseismic (Alaneme and Okotete 2018). The occurrence of tremors in this relative aseismic justify the interest given to this research (Goki *et al.,* 2020). Researchers of tremor occurrences in Nigeria did not consider the factor of crustal thickness. According to work by *Hongbo et al.,* (2011), the percentage of crustal displacement caused by wenchuan earthquake is much at thin crustal thickness area than at thick crustal thickness area.

Geology of the study area: The gravity data covers an area of about 289,059.3 km. The survey is part of Benue and Ebonyi states. The survey was conducted by Nigerian Geological Survey Agency. Determination of the crustal thickness using ground gravity data of parts of Ebonyi and Benue statse; bounded by latitudes 5.30′ N and 8^0.30′ N and 7^0.30′ E and 10^0.00′E and is situated within the Southern Benue Trough. The Benue Trough structure is comprised of pull-apart sub-basins or grabens (Fig. 1) resulting from sinistral displacements along pre-existing NE-SW trending transcurrent faults (Benkhelil and Robineau, 1983; Guiraud, 1990; Guiraud *et al*., 1992). Spanning over 1,000 km in length and up to 250 km in width, the trough is an elongate intracratonic structure developed within the Pan-African mobile belt as a rift structure (Nwajide, 2013). The trough's formation is linked to the rifting of Central West Africa during the Cretaceous period and the consequent crustal stretching of the African Plate following the initiation of the proto-equatorial Atlantic (Fitton, 1983; Genik, 1992). The Benue Trough's distinct evolution is marked by folded sediments and folding axes parallel to its length (Fitton, 1980), evolving into an intercontinental fold chain through a sequence of tectonic events from the Late Jurassic. The structure was affected by a compressional event in the Cretaceous, resulting in widespread folding and faulting, and was slightly modified by Tertiary extensional tectonics (Benkhelil and Robineau, 1983). Overlying the facies of the Lower Benue Trough is the Anambra Basin which consists of Campanian to Early Paleocene (Danian) lithofacies. Many authors: Akande and Erdtmann (1998), Obaje *et.al*., 1999) etc considered the Anambra basin as part of the Benue Trough on the premise that is a consequence of the compressional history/stage of the trough. Being a relocated structure that developed after the compressional state, they implied that it was logical to include the Anambra Basin in the Benue Trough. However, Nwajide, 2013 and some authors disagree with this proposition by showing that the Anambra basin is a distinct and well demarcated lithostratigraphic entity overlying the southern Benue Trough and is in turn overlain by the Niger Delta basin. The origin of the basin is generally believed to be linked to the Santonian tectonics of the Abakaliki Benue Basin, during which an N-S compression between the African and Europeans Plates folded the Abakaliki Anticlinorium (Burke, 1971).

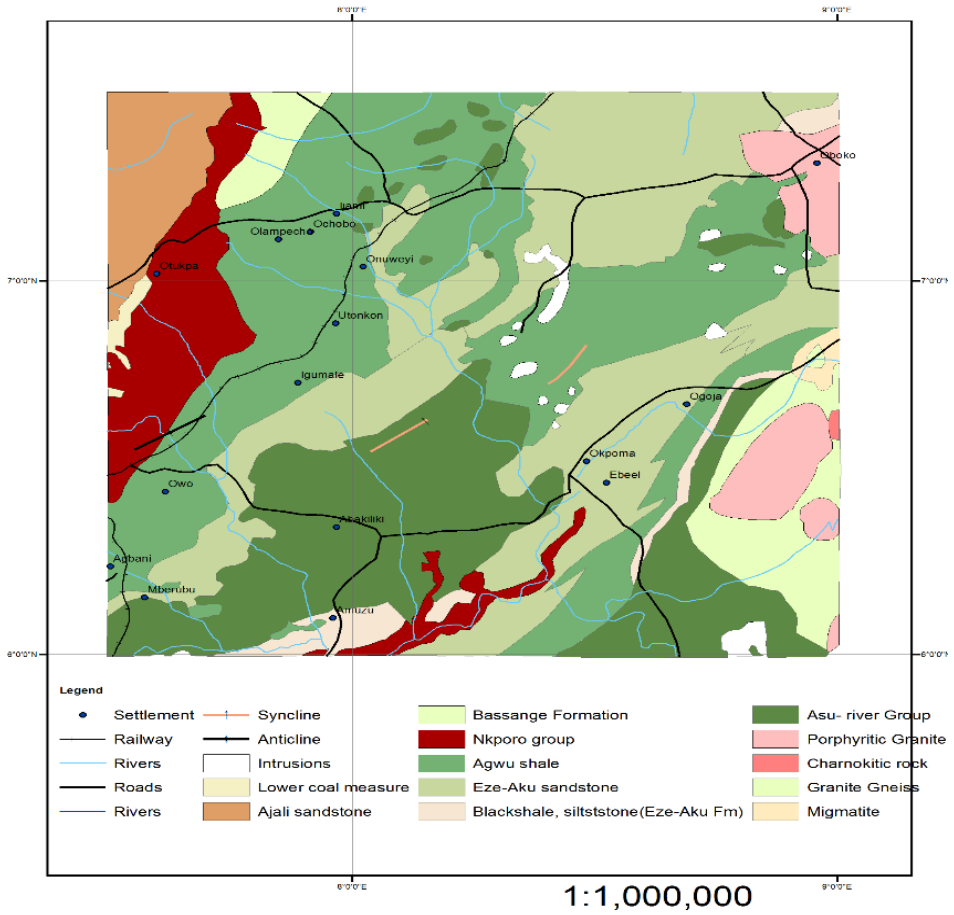


Fig. 1: Geology of the study area

2. Meterial/Theory and Methods

Materials used for this research study including the following: Gravity data of the study area, Oasis Montaj software 8.2, Excel 2013 softwares and Work station (Laptop). The Bouguer gravity anomaly map of the study area was prepare from the ground gravity data which was acquired by the Nigeria Geological Survey Agency (NGSA).

Methods

The study applied two different methods to determine the crustal thickness of the study area. These include:

I. The power Spectral Analysis
II. The Empirical Relation

Determination of Crustal thickness by the Power Spectral method

The power spectral method is an extensively employed technique for determining the depths of geological sources and detecting discontinuities, based on the properties of the energy spectrum of extensive gravity data sets. Gravity data plays a crucial role in determining the depth to the Mohorovicic discontinuity. The 2-D Fast Fourier Transform is utilized to transform gravity data from the space domain to the wavenumber

domain for frequency analysis (Saada *et al.*, 2013), facilitating consideration of the source anomaly's average depth. Eight blocks were created from the main Bouguer map within the OASIS MONTAJ 8.2 environment for efficient crustal thickness calculation and discontinuities determination.

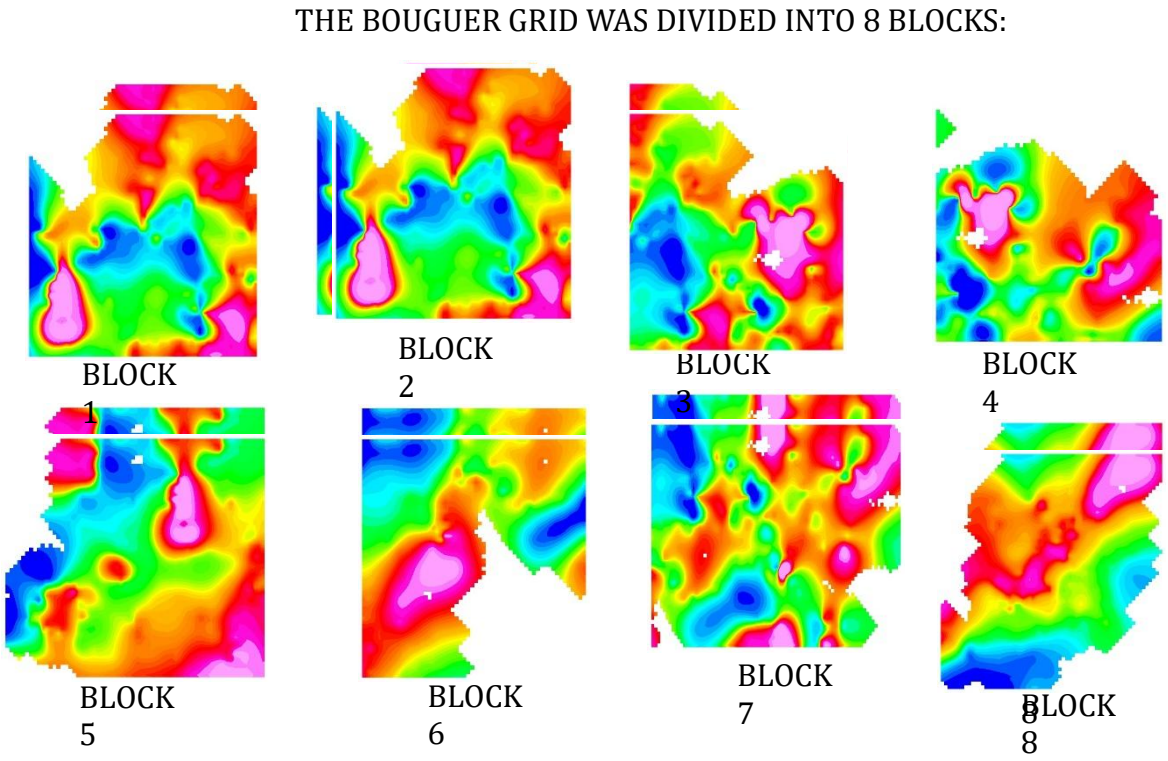


Fig. 2: Bouguer Grid Blocks used for Spectral Analysis

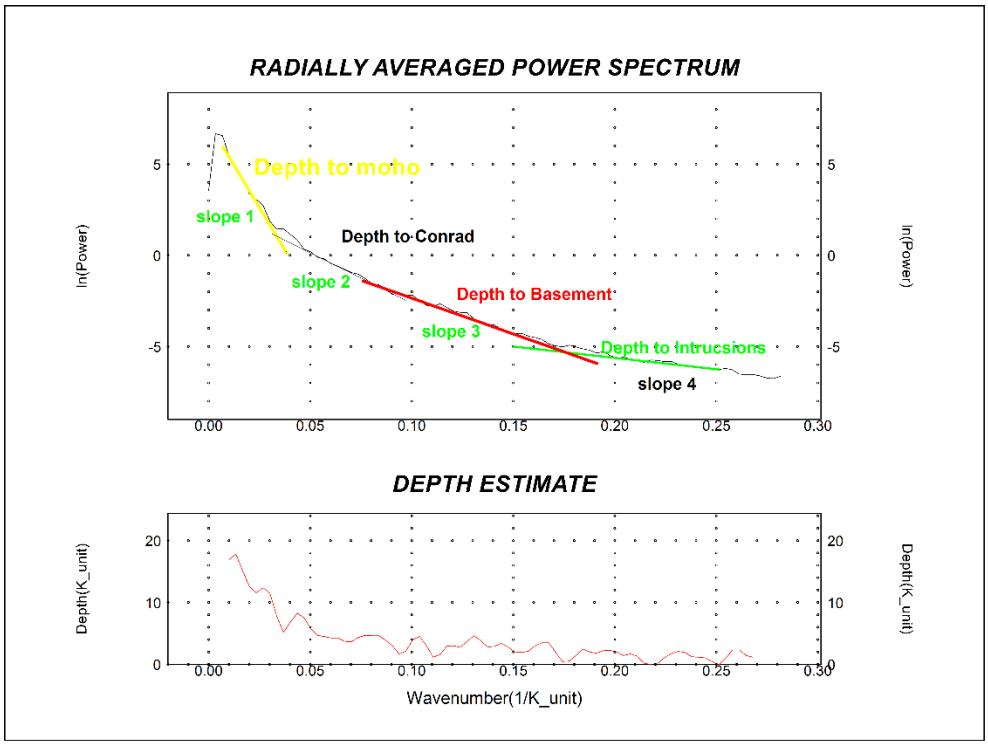


Fig. 3: Radially averaged Power Spectrum used in calculating the Discontinuities.

On the plot, four straight lines segments were displayed and labelled 'Depth to Moho', 'Depth to Conrad', 'Depth to basement' and 'Depth to Intrusion'. The slopes of the different segments provide an estimate of the thicknesses of the boundaries. The boundary between the crust and mantle, known as the Moho, is calculated using Slope (1), while Slope (2) determined the boundary between the upper and lower crust, known as the Conrad, Slope (3) calculated sedimentary thickness while slope (4) calculated the depth to intrusion (Fig. 3). They are calculated using the following equation $H = -\frac{slope}{2\pi}$. Fig. 3 is one of the eight plots of the logarithm of the power spectrum against the frequency. The plots were drawn in order to calculate approximately the average crustal thickness.

Use of Empirical relations methods in crustal thickness Determination

Three empirical relations, developed by Demenistskaya (HD, 1958), Woolard (HW, 1959) and Woolard and strange (HWS, 1962) relating bouguer Gravity with crustal thickness were used to calculate the crustal thicknesses within the study area (Megwara *et al.,* 2014). Three empirical relations, developed by the tectonic implication of the crustal thicknesses of the different areas was established'relating bouguer gravity with crustal thickness were used to calculate the crustal thicknesses within the study area (Megwara *et al.,* 2014). The Bouguer gravity anomaly data was imported into an Excel sheet, and values were substituted into the empirical relation, and the crustal thicknesses of the study area were calculated (Azuwike *et al*., 2018). After calculating the crustal thickness using the empirical relations, the average value was computed and gridded (Fig. 6). The empirical relation equations are as follows:

$$HD = 35\left(1 - TANH\left(0.037BG\right)\right) \quad (1)$$

$$HW = 32.0 - 0.08BG \quad (2)$$

$$HWS = \frac{40.5 - 32 - 50TANH\left(\left(BG + 75\right)\right)}{275} \quad (3)$$

Where HD, HW and HWS are in km and BG (Bouguer) is in mGal.

Determination of the crustal thickness determination is useful in deducing the geological history of an area, and in tectonic study (Udensi, 2000).

3. Results and Discussion

Interpretation of Bouguer Anomaly map

The Bouguer gravity anomaly data of the study area were gridded. The negative anomalies observed on the Bouguer map are attributed to low-density bodies within that area or due to the existence of a huge down wrap of sediments in that particular area while positive Bouguer anomalies are attributed to high-density bodies in the area. High closures are attributed to intrusive rocks that intruded into the sedimentary cover while the low Bouguer anomalies may be due to basement relief (See Fig. 4). Fig. 4 is the contour version of Bouguer anomaly map and shows a lot of closures and the closures observed on the map signify structural alignment (Azuwike et al., 2018) to the tectonic activities that must have taken place in the study area. The deep density structures produce gravity anomalies with a long spatial wavelength, while the shallow density

structures produce gravity anomalies with short spatial wavelengths. The low density corresponds to the sedimentary fill of the Benue Trough grabens (Bezák1 *et al.*, 2023).

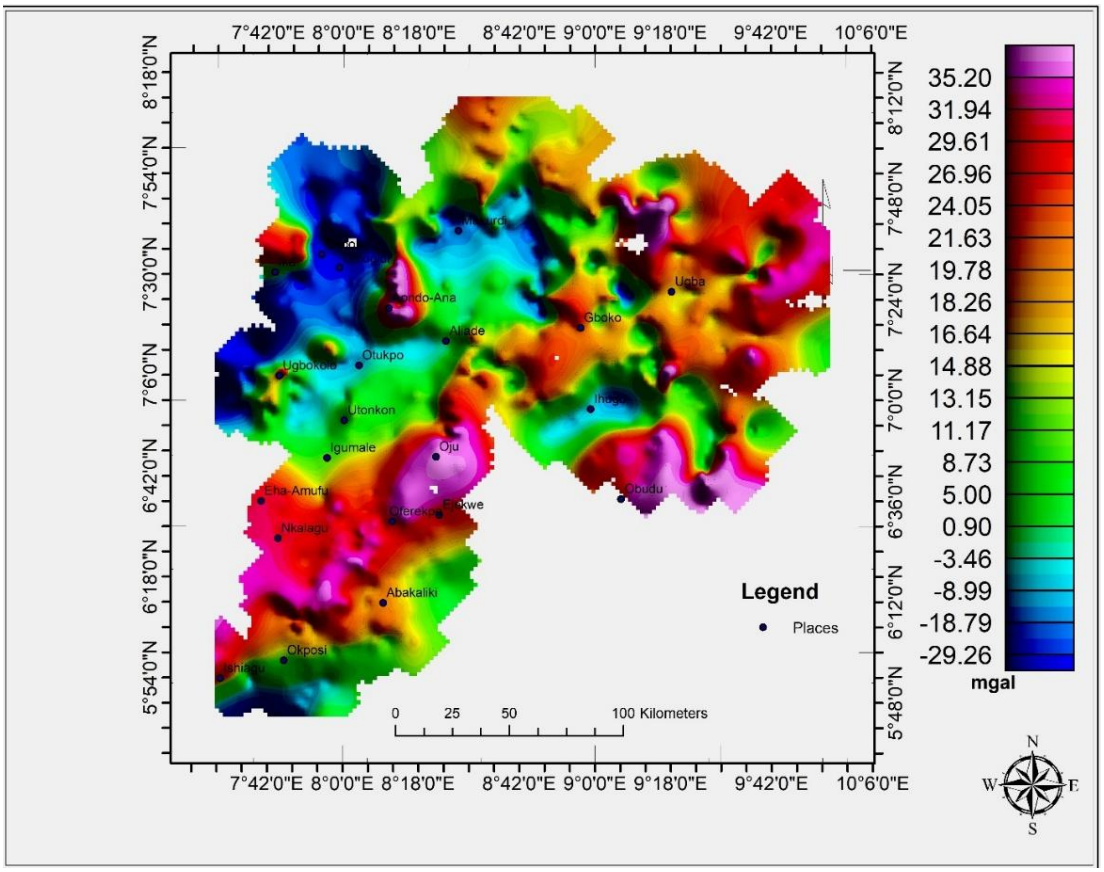


Fig.4: Bouguer Anomaly Map

More negative Bouguer anomalies are associated with thicker crustal regions, such as mountains and continental crust, whereas less negative or positive anomalies are indicative of thinner crust, typically found in ocean basins and rift zones, due to the displacement of dense mantle creating gravitational deficits. The gravity method of geophysical survey depends on Earth's gravitational field to measure and define anomalous density within the Earth. Gravity anomalies are computed by subtracting a regional field from the measured field. This separation between the regional field and the measured field yields the Gravity anomalies that connect with source body density variation (Donald *et al*., 1995).

Crustal thickness from Empirical relations methods.

The average crustal thickness computed using empirical relations ranges from 20.0km to 41.25km, with a mean value of 31.58km. The gridded form of the average crustal thickness map of the study area using the empirical relation method is shown in Fig. 5. Table 1 shows different areas and their corresponding crustal thicknesses. Crustal thickness is inversely related to the Bouguer anomaly value (See Fig. 4 & Fig. 6). The high crustal thickness in Fig. 6 may be attributed to high-density bodies in that location or to low sediment accumulation, while the low crustal thickness may result from low-density bodies in that area or from high sediment accumulation.

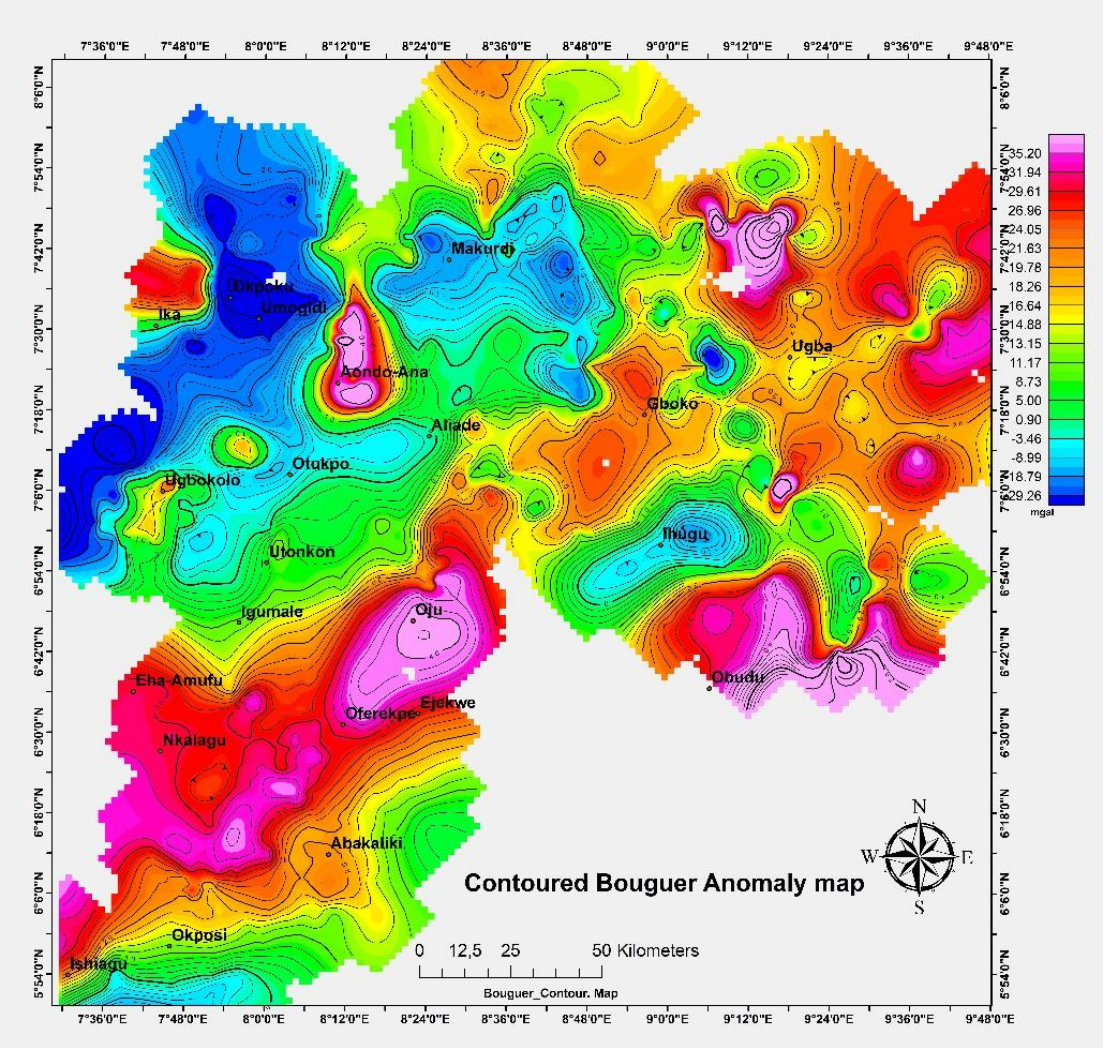


Fig. 5: Contoured Bouguer map

Crustal thickness by the Power Spectral method

Table 1 shows the average values of the Moho, Conrad, sedimentary thickness, and depth to intrusion obtained by dividing the Bouguer gravity anomaly map of the study area into eight sections. The average crustal thickness (depth to 'Moho') estimated by spectral analysis ranges from 15.99 km to 33.34 km, depth to conrad values range between 5.60 and 13.20 km, depth to the basement values range between 4.28 and 8.39 km, while depth to intrusion is between -3.45 and 4.42 km.

Moho depth (Crustal thickness) of 25-30 km are consider shallow while Moho depth greater than 30 km are consider to be deep (Matsubara *et al.*, 2019). The average crustal thickness computed using empirical relations ranges from 20.0 km to 41.25 km, with a mean value of 31.58km, while values computed using spectral analysis ranges from 15.99 km to 37.34 km. Thus, the crustal thickness of the study area is considerably thick in some places and also revealed evidence of thinned crust within the Benue trough (Ajakaiye *et al.,* 1987). According to some past workers, crust is generally thicker, around 35–41 km, under the North-Central basement complex and shallower, around 23–30 km, in the Benue trough (Abdullahi *et al.,* 2019, Jimoh and Udensi, 2024; Anudu and Obrike, 2024).

Countries prone to earthquakes with their crustal thickness, including India (with a crustal thickness of 177-289 km), China (64-94 km), Mexico (43- 83 km), Japan (29km to 63 km), and Congo (46 km-92 km), have crustal thicknesses greater than the study area. A comparison with countries prone to earthquakes reveals that most of them have greater crustal thicknesses, implying that crustal thickness alone is not a definitive indicator of tectonic stability. The instability observed in some regions of Nigeria experiencing tremors may be due to localized subsurface faults (Goki *et al.,* 2020).

Table 1: Crustal thicknesses of various locations at the study area

Places	**Crustal thickness (Km)**
Okpuk	36.73
Umogidi	35.93
Makurdi	34.19
Ihugu	34.40
NE of Gboko	31.00
Aoado-Ano	27.93
Obudu	29.54
Oju	29.28
Oferekpe	28.97
Eha-Amufu	30.19
Nkalagu	29.85
Ejekwe	28.93
Abakaliki	31.81
Utonkon	32.43
Aliade	32.82

Table 2: Values of the Crustal Thickness and other Discontinuities of the Study Area

BLOCKS	DEPTH TO MOHO(KM)	DEPTH TO CONRAD(KM)	DEPTH TO BASEMENT(KM)	DEPTH TO INTRUSION(KM)
BLOCK 1	23.60	9.67	4.28	1.23
BLOCK 2	17.07	7.15	5.30	1.83
BLOCK 3	15.99	9.16	5.35	3.30
BLOCK 4	33.34	9.41	6.95	4.42
BLOCK 5	33.18	11.12	6.95	1.35
BLOCK 6	29.61	11.74	5.13	-3.45
BLOCK 7	19.81	5.60	4.67	3.67
BLOCK 8	24.50	13.20	8.39	4.42

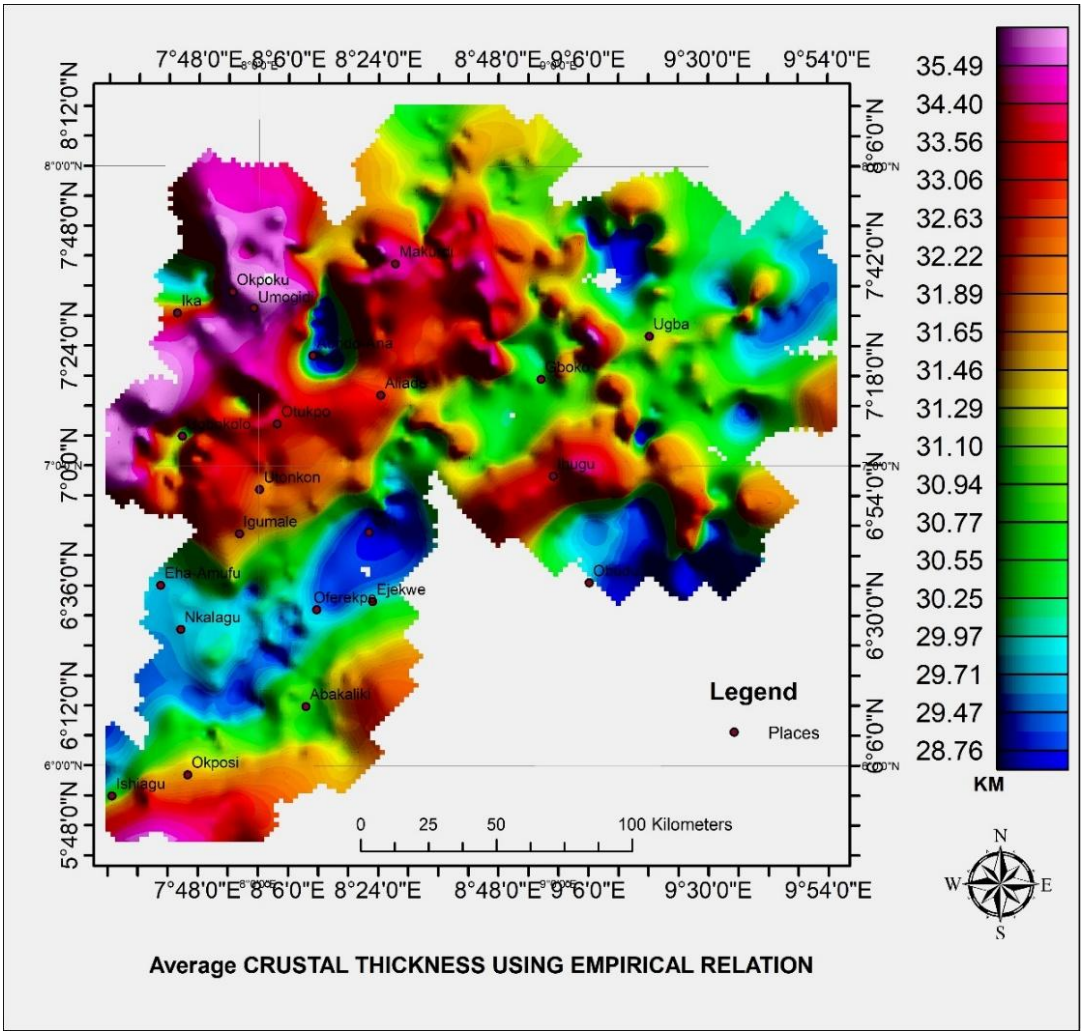


Fig. 6: Crustal thickness estimation from Average values of the Empirical Relations

4. Conclusion and Recommendations

The empirical relation method results shows that the average crustal thickness obtained ranges from 20.01 to 41.24 km, with a mean value of 31.58km which is within the reasonable range compare to the Moho depth estimated from the spectral analysis. Low bouguer (negative anomalies) anomaly areas signify thick crust while high bouguer (positive anomalies) anomaly areas signify thin crustal thickness. The negative anomalies noticed on the Bouguer map are attributed to low-density bodies while the positive anomalies are due to high-density bodies. The Conrad discontinuity ranges in depth from 5.60 to 13.20km, the depth to basement ranges in depth from 4.28 km to 8.39 km, while the depth to intrusion ranges in depth from -3.45 km to 4.42 km. The results indicate that the area is tectonically stable.

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References

Abdullahi, M., Upendra K. S. & Umar, M. M. (2019): crustal structure of southern Benue Trough, Nigeria from 3D inversion of gravity data, Journal of Geology and mining research Geology (4):39-47

Ajakaiye, D.E., Daniyan, M.A., Ojo, S.B. and Onuoha, K.M. (1987) The July 28, 1984 South Western Nigeria Earthquake and Its Implications for the Understanding of the Tectonic Structure of Nigeria. Journal of Geodynamics, 7, 205-214.

Akande, S.O & Erdtmann, B.D., (1998): Burial metamorphism (thermal maturation) in Cretaceous sediments of the southern Benue Trough and Anambra Basin, Nigeria. Geol.en Mijnbouw, (7)131 – 144.

Alaneme, K.K. & Okotete, E.A. (2018) Critical evaluation of seismic activities in Africa

and curtailment policies – a review. Geoen Disasters 2(24):1–17

Anudu, G.K. & Obrike, S.E. (2024) Upper Lithospheric Structure of the Middle Benue Trough, Nigeria, Derived from Analysis of Satellite Gravity Data. Journal of Mining and Geology. (57) 5

Azuwike, M. Chigozie, A. Alkali, E. E. Udensi, K. A. Salako & A. A. Rafiu (2018). Determination of the Crustal thickness within Northern Bida Basin, North Central Nigeria, using Gravity data. FUW Trends in Science & Technology Journal 3 (2): 570 – 571.

Benkehelil, J. (1986). Structure et evolution geodynamique du basin intracontinental de la Benoue (Nigeria). Unpubl. Thesis, Nice et Elf Nigeria SNEA (P), (2) 231p. In Nwajide, C. S. (2013): Geology of Nigeria's Sedimentary Basins. CSS Bookshops limited Lagos Nigeria.

Benkehelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough (Nigeria) Journal of Africa Earth Sciences (8): 251-282.

Bezák1, V., Bielik, M. Marko, F. Zahorec, P., Pašteka, R., Vozár, J. & Papčo, J. (2023). Geological and tectonic interpretation of the new Bouguer gravity anomaly map of Slovakia

Burke K., Dessauvagie T. F. J. & Whiteman, A. J. (1971). Opening of the Gulf of Guinea and geophysical history of the Benue depression and Niger delta. Nature 233: 51–55.

Demenitskaya, R. M. (1958). Planetary structure and their reflection in Bouguer anomalies. Geology Bulletin, 8, 52-62

Don, L, Sheldon, J & Marvin E. K. (1933). Physical Geology 5th Edition Prentice Hall Inc. Eaglewood cliffs, New Jersey 489P.

Donald, B.H., Douglas, P.K. & David, C.C. 1995. Geophysical methods in exploration and mineral environmental investigations. US Geological Survey, 19 – 27.

Fitton, J.G (1980): The Benue Trough and Cameroun Line: a migrating rift system in West Africa Earth and Planetary Sci. Lett. (52): 132-138.

Fitton, J.G (1983): Active versus passive continental rifting: evidence from the West African Rift system. In: Nwajide, C. S. (2013): Geology of Nigeria's Sedimentary Basins. CSS Bookshops limited Lagos Nigeria. 565p.

Genik, G.J., (1992). Regional framework, structural and petroleum aspects of rift basins in Niger. Chad and the central African Repubulic (CAR). Tectonophysics (213) 169-185.

Goki, N. G., Onwuka, S.A., Oleka,A.B., Iyakwari, S.,Tanko, I.Y., Kana, A. A., Allu Augustine Umbugadu, A. A., & Usman, H.U. (2020). Preliminary geological evidence for multiple tremors in Kwoi, Central Nigeria. Geoenvironmental Disasters. (7):22.

Guiraud, M. (1990) Tectono-Sedimentary Framework of the Early Cretaceous Continental Bima Formation (Upper Benue Trough, Northeastern Nigeria). Journal of African Earth Sciences (10):341-353.

Hongbo, T., S Chongyang, S., Songhai, X. & Guangliang, Y. (2011). Influence of crustal layering and thickness on co-seismic effects of Wenchuan earthquake Geodesy and Geodynamics 2011, 2(1):47-54.

Jimoh, N. L., & Udensi, E. E. (2024). Assessment of the Crustal Thickness within Southern Bida Basin and Surrounding Basement Rocks, North Central Nigeria, using Gravity Data. Nigerian Journal of Physics, 33(2)123-136.

Megwara, U. & Udensi, E.E. (2014). Structural analysis using aeromagnetic data: Case study of parts of southern Bida Basin, Nigeria and the surrounding basement rocks. J. Earth Sci. Res., 3(2): 27-42.

Nwajide, C. S. (2013): Geology of Nigeria's Sedimentary Basins. CSS Bookshops limited Lagos Nigeria.565p.

Obaje, N.G., Funtua, I.I. Ligouis, B. & Abaa, S.I., (1999): Organic Maturation and Coal-Derived Hydrocarbon Potentials of Cretaceous Coal Measures in the middle Benue trough of Nigeria, J. mining and Geology 34(1): 7-18.

Saada, D.U., Erdtmann, B.D. & Scheeder, G. (2013). Structural analysis using aeromagnetic data over Bida Basin, Nigeria and the surrounding basement rocks. J. Earth Sci. Res., 4(3): 7-42.

Udensi, E.E. (2000). Estimation of crustal thickness of Minna: Preliminary investigation. J. Sci., Techn. & Maths. Edu. (JOSTMED), 3(1): 10-17.

Walter D. (2003). Encycloprdia of physical Science and Technology (Third Edition)

Woolard, G. P. (1959). Regional variation in gravity, in the Earth's crust and upper Mantle. Journal of Geophysics, 13, 320.